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NASA sustaining grant NGL 05-020-014 is the major research support to the Stanford Center for Radar Astronomy (a joint venture between Stanford University and the Stanford Research Institute). The progress and direction of research supported by these funds is reviewed semi-annually in concise status reports such as this one and in expanded form in the annual proposal for continued support. The following sections are intended to bring the reader up to date on faculty, research associate, and student activities since that time.

Mariner V

Comparison of the Russian Venera 4 and American Mariner V results has led to several new conclusions. These were published in Science of November 8, 1968 under the title of "Venus: Lower Atmosphere Not Measured". The abstract of that report is included below:

> Abstract: The common ranges of pressure and temperature of the atmosphere of Venus measured last October establish the connection between the Soviet Venera 4 altitude scale and the United States Mariner V radial scale. But if the Venera 4 measurements extended to the surface, as claimed, this comparison implies a radius of the planet which is about 25 kilometers greater than the radius deduced from Earth-based radar data. This impasse has been resolved in favor of the smaller value by a new determination of the radius which is more direct than the method used in deriving the radar radius, and which involves concurrent ranging from Earth both to Mariner V near encounter and to the surface of Venus. It is concluded that neither spacecraft reported on atmospheric conditions near the level of the mean surface, but extrapolations of the measurements yield surface values for mid-latitudes of 100

atmospheres pressure (within a factor of 1.5) and 700°K temperature (within 100°), in distinction to the Soviet values of 19 ± 2 atmospheres and 544° ± 10°K. The higher values support radiometric and radar data on temperature and atmospheric absorption. It appears that the Soviet probe was not designed to work through such a thick atmosphere. A particularly simple (times two) ambiguity in the Venera 4 altimeter reading suggests itself, since this would explain the reason for the supposition that the probe reached the surface.

Analysis of the Mariner V differential Doppler and amplitude data obtained during the Venus encounter has now been completed. The study of the data yielded the electron density distribution in the ionosphere and the temperature and pressure profiles for the lower neutral atmosphere of Venus. A final report describing this work is in press.

The 423.3 MHz ray path probed down to within about 35 km of the surface of Venus before loss of lock occurred during immersion. Signal reacquisition took place as the propagation path reached the 47 km altitude level on the emersion side. The pressure and temperature profiles for the neutral atmosphere above these levels were determined by fitting the defocusing produced behind model atmospheres to the amplitude changes observed on the 423.3 MHz receiver channel. The amplitude measurements at the lower frequency are less precise but do agree with the results obtained at the higher frequency. The results indicate that the dayside atmosphere of Venus may have been some 30°K colder than the nightside.

For the upper atmosphere the analysis shows that Venus has ionization peaks near 140 km altitude on both the sunlit and dark side. On the dayside the ionosphere appears to terminate abruptly in a plasma pause near 500 km

altitude while on the dark side the ionization may extend out in a cylindrical wake to 4000 km altitude or more.

Martian Atmosphere Simulation

Knowledge of the refractive index of CO_2 at low temperatures and pressures is required in the interpretation of occultation data from planetary probes such as Mariners IV and V. Data from these missions have generally been interpreted using values measured at standard temperature and pressure and extrapolated to Martian conditions.

This experiment has now been completed. A circular cavity with a resonant frequency of 2258 MHz in the TE013 mode was constructed. The cavity Q achieved was 113,000. An insulated vacuum chamber and pumping and cooling facilities were constructed and the refractive index of CO_2 was measured over the range from room temperature and pressure down to the sublimation point of CO_2 at 5 millibars.

The ambient condition measurement when extrapolated to Stanford temperature and pressure agrees with the results of other experimenters at 24 gHz and optical wavelengths. Preliminary computations using the low temperature and pressure data show that the refractive index of CO_2 remains unchanged all the way to the sublimation point. This means that the use of the classical CO_2 refractive index extrapolated to very low temperatures and pressures is valid.

General Relativity

Over the years several proposals have been made regarding the possibility of using radio frequency measurements on spacecraft approaching solar

occultation as a test of general relativity. These have naturally been preceded by studies of other methods of doing such measurements.

There are three classical tests of general relativity which could be conducted by observations from the Earth's surface: measurement of the gravitational red shift, the deflection of light by the Sun, and the precession of the perihelion of Mercury. With earth satellites, it has been suggested that one might test gyro precession or clock speed to provide other tests of the theory. None of these tests has yet yielded a decisive result.

The bending of starlight has been measured by comparing pictures of a star field with and without the Sun in the center. The bending causes the stars to appear farther from the Sun. Unfortunately there are many sources of error which are comparable to the effect being measured, and so the results have not been sufficiently accurate to permit a good test of the theory. (They are at least good enough to show that Newtonian mechanics do not apply.)

During a symposium report given by Professor Schiff of our Physics Department, it became apparent to one of us that there was a possible way of measuring starlight bending which could be extremely accurate. This method must be implemented in an orbiting spacecraft, since it involves a simultaneous view of two stars which are about 180° apart. (This could not be done from the surface of Earth or Moon.)

Initial calculations have been encouraging. The principle of the test involves the comparison of the view of the same two stars before and after the image of one passes near the Sun. This offers two advantages:

1) We do not need accuracy or precision, but only repeatibility. The apparatus faults will affect both image pairs in the same way, except for those changes caused by equipment dimensional change or pointing errors. These appear to be small.

2) The effect to be measured is doubled by virtue of the fact that the bending is in opposite directions in the two measured data and so the difference angle is twice the bending angle.

Mariner '71

The Stanford experiment has been selected for the Mariner Mars 1971 orbiters. Funding under letter contract from JPL will commence in January 1969 and a detailed and final proposal will then be generated. Responses from two industrial organizations for cost and weight estimates to do the experiment at higher frequencies and wider bandwidths were discouraging. Faced with doubling of cost and weight we have decided to use existing hardware designs for our two channel package, but to have any two of three input frequencies selectable. This will eliminate differential bending, or caustic, problems for the planet's dayside ionosphere by using two high frequencies while allowing interplanetary density and planetary wake measurements to be performed on thw two lower frequencies.

Instrument Development

Several possible modifications to the Stanford Pioneer and Mariner type instruments have been investigated with the goal of increasing accuracy while taking advantage of the rapidly advancing integrated circuit technology.

Though specific proposals for funding such efforts have been turned down in the past it is obvious from the rapid pace of and compressed delivery schedules for flight programs that continuous development is necessary.

One of the more promising investigations conducted during this report concerns the modulation phase measuring circuitry. The method provides unambiguous 0 to 360 degree measurement of phase unlike the current circuitry which goes only to 180 degrees. This capability is particularly important during solar plasma "pulse" events when data can be lost if the ground-based transmitter operators miss a phase dial reset due to teletype outage or other operational problems.

Student Activities

The following brief reports are representative of graduate student activity.

Ronald Arps (Ph.D.)

A study of compression codes for the transmission and storage of digital images is being made. The emphasis is on two-level images of printed matter. To acquire representative input statistics, data is being examined from documents passed through a scanner/computer/printer system. This system was built previously to explore the variations of character legibility with resolution. This work was reported last June in a joint paper to the 1968 IEEE International Conference on Communications. Since then, I have extended this work with a theoretical model for the threshold of character legibility and an analytical model fit to the empirical data.

It was anticipated that the statistics from characters scanned at optimal resolution would reflect their structure, by showing dependency between "runs" of black and white in line-by-line scanning. These dependencies have been found and measured, indicating potential savings over previous compression schemes (based on independent "runs"). Exploration of two-dimensional scan patterns shows even greater potential for compression, along with much simpler encoder/decoder designs.

A model for the effects of burst noise on a run-length-code has also been simulated using the above test system. Measurements with printed documents were made to determine the loss in character legibility for different states of this burst-noise model.

Jose Pomalaza (Ph.D.)

As described in the Radioscience Laboratory Report no. SU-SEL-68-038, phase path measurements of the transmission between two satellites through the Earth's atmosphere contain information of the pressure and temperature profiles of the lower atmosphere. A procedure was developed to invert the phase path data and thus to obtain the pressure and temperature profiles. This procedure is based on the Least Mean Square (LMS) technique.

In the process of inversion, it is very important to have a good parametric representation of the pressure and temperature. Only a simplified inversion problem was treated at this stage. The data was obtained by ray tracing through the standard atmosphere and the model temperature profile was described by segments of straight lines. The pressure was obtained using a surface pressure and the hydrostatic equation. The inversion

procedure worked satisfactorily, giving back a good approximation of the standard etmosphere.

Empirical orthogonal functions were studied as a means of obtaining a better parametric description of the temperature profile, as suggested by many authors. They will be used in future inversion problems.

A subroutine to compute atmospheric attenuation in functions of pressure and temperature in the 10 gHz region was developed. This attenuation includes the oxygen, water vapor and liquid water attenuations.

The use of microwave radiometer is being investigated in order to obtain complementary information which, with the attenuation and phase path measurements, would permit us to correct for the water vapor effects in the lower troposphere. Multipaths due to refractivity gradients in the lower tropopause are also being investigated. Amplitude and phase scintillations are also being studied as they have a potential to provide information about the water vapor.

Richard Simpson (Ph.D.)

The following work was done primarily for a lunar bistatic radar project being carried out under separate funding but has several applications.

If the characteristics of a signal incident on a planetary surface are known, they can be compared with those of the reflected signal to give some indication of the behavior and properties of the specular region. The particular problem here was to find a computer simulation of the incident electric field by modelling the antenna of an orbiting spacecraft (Explorer XXIV with a modified turnstile antenna in this case). The physical

dimensions and orientations of the elements were known and rough, pre-launch, measured patterns were available for comparison.

Starting with infinitesimal current elements, four current roots were built up. Rod lengths and their positions, orientations, and electrical phases were preset in constant matrices. Variables were the two polar coordinate angles, theta and phi. The program sums the contributions from each element and produces the resultant electric field.

Virtually any antenna array expressable as the sum of no more than four linear current elements can be simulated in this way (more elements could be added without major revision of the program). The pattern in any plane can be found by converting the points in that plane to corresponding theta and phi.

Dipole, dipole pair, broadside, and end-fire configurations have been checked as well as the turnstile and modified turnstile; results have been satisfying. Some work has been done on a companion program to modify the theoretical turnstile fields to match the pre-launch measured values, but this has not been completed.

Wellington Yu (Ph.D.)

A report entitled "Circuit Synthesis Utilizing Digital Variable-Precision-Integrating and Summing Elements", (SU-SEL-68-084) was completed during the last reporting period. It is a feasibility study on realizing real-time network functions by using a minimum number of the proposed semiuniversal digital integrated circuit modules (digital integrating and summing elements).

For high-speed operation, the proposed digital integrator has been implemented by the modified trapezoidal-integration method and by the signed-digit number system. A technique to obtain variable precision has also been achieved.

Optimization is performed on the digital modules, subject to a minimum-cost criterion, resulting in a synthesis procedure for obtaining network realization with a minimum number of digital modules as well as with the best performance. Essentially, the transfer function can be realized by the digital modules alone; however, the immitance function or the conventional-element replacement can only be made possible with the help of the analog-to-digital incremental converter and the digital to-analog converter.

Richard Koralek (Ph.D.)

Optical techniques are presently being used for several types of data processing. Optical systems are well suited for applications such as pattern recognition, in which input and output data may be visual, and for operations such as Fourier transformation and crosscorrelation. The success of these techniques leads to the idea of a general purpose optical computer.

The advantages of an optical computer over its electronic counterpart would be speed and size. The speed of an all-optical computer would be limited only by the speed of signal propag ation. The parallel processing abilities of optical systems would make possible a further increase in speed over electronic computers as well as a decrease in size.

A study of possible optical realizations of Boolean functions suggests that a different approach must be used for an optical computer than would be used for an electronic one. The advantages of different logic systems, such as majority logic of multi-state logic, are being studied.

Computer organizations very different from those presently in use will also be examined, since an optical processor would logically be a more parallel than serial machine. Finally, the applications of such an optical computer, particularly in the fields of real-time signal processing, will be investigated.

Richard Mayes (M.A.)

I have been working on the design and construction of the hardware for the new integrated version of the meteor winds radar station. A few changes in the final versions of certain subassemblies have slowed progress, but as they are finalized, duplications can easily be made. At present, parts of the frequency synthesizer and the logarithmic analog-to-digital converter have been completed, and the control circuits are in the testing stage. The finished machine is still over the horizon, however.

Yuen Chung Chin (Ph.D.)

It is well known that the characteristics of received polarization of meter wave radiation can reveal the structure of the magnetic field at the source and/or field along the path of propagation. The Jupiter polarimeter project has concentrated on solar radiation in recent years. Since September of this year, the conversion of data from analog to digital tapes

has been performed on the Sigma 5 instead of the IBM 1620. The Sigma 5 allows three times the resolution of the former computer.

The general characteristics of spectral Type III bursts which have been recorded indicate high polarization. Some peculiar events have also been recorded with the polarization changing from left-handed to right-handed during the storm period. A model has been composed and further analysis is being conducted. Results of the data concerning Type III bursts will be available in report form within several months.

Michael Green (M.A.)

A program is being developed which will use the SDS Sigma 5 computer to produce drawings on an oscilloscope display. The program is designed to make use of either a polaroid camera to record the display or a 35-mm camera for producing "computer movies". Since the program will be for general purpose use, a prime effort is being made to make it easy to use.

A group of user-oriented subroutines for the SDS Sigma V computer are being developed for use in producing computer drawn pictures. These programs use the computer's digital-to-analog capabilities to produce an oscilloscope display which is suitable for photographing. It is also planned to use the D-A output to control the film transport and shutter of a 35-mm camera so that computer generated "movies" may be produced. Since these programs are intended for general purpose use, a prime effort is being made to make them easy to use.

Daniel Ingalls (Ph.D.)

The last report mentioned the project of lunar limb study by observation of AIMP satellite transmissions at the time of occultation by the Moon. Since the signal tapes appeared unreliable at that time, I have since then assembled a receiving station to furnish data on a "fresh daily" basis. The previous anomaly of short term variations in signal still persists, and one is led to attribute these to improper modulation in the spacecraft. The difficulties of removing such variations are great, and may not be practicable. However, the recent lunar orbit by the Apollo spacecraft may furnish data tapes of great interest to the occultation study owing to the greater transmitter powers and antenna gains involved and especially to the freedom from antenna rotation perturbations.

I have been recently adapting and creating software for the Sigma V computer acquired by the Center. Hopefully soon we will have the facility to embark on computer reconstruction of scattering surfaces by coherent detection. The programs, once developed, can be applied in such different fields as acoustics, holography and radar studies of planets.

Publications

Dyce, R. B., Radar studies of the planets, from Surfaces and Interiors of Planets and Satellites, ed. A. Dollfus, Academic Press, Paris (in press).

Eshleman, V. R., The atmospheres of Mars and Venus, Scientific American (in press).

Fjeldbo, G., Ionospheres of Venus and Mars, from Encyclopedic Dictionary of Physics, ed. J. Thewlis, Pergamon Press, Oxford (in press).

Fjeldbo, G. and V. R. Eshleman, The atmosphere of Mars: radio occultation measurements and interpretations, from The Atmospheres of Venus and Mars, ed. J. C. Brandt and M. B. McElroy, Gordon and Breach Science Publishers, 225-240, New York, 1968.

Tyler, G. L., Oblique-scattering radar reflectivity of the lunar surface: preliminary results from Explorer 35, J. Geophys. Res., 73, 7609-7620, December 1968.

Eshleman, V. R., Fjeldbo, G., Anderson, J. D., Kliore, A. and R. B. Dyce, Venus: lower atmosphere not measured, Science, 162, 661-665, 8 November 1968.

Tyler, G. L., Brewster angle of lunar crust, Nature, 219, 1243-1244, 21 September 1968.

Conklin, E. K. and H. T. Howard, Simultaneous observations of a pulsating radio source over a 5,000 km baseline, Nature, 219, 1238-1239, 21 September 1968.

Koehler, R. L., Radio propagation measurements of pulsed plasma streams from the Sun using Pioneer spacecraft, J. Geophys. Res., 73, 4883-4894, 1 August 1968.

Fjeldbo, G. and V. R. Eshleman, The atmosphere of Mars analyzed by integral inversion of the Mariner IV occultation data. J. of Planetary and Space Sci., 16, 1035-1059, July 1968.

Bollay, W. and B. B. Lusignan, Systems engineering, J. of Engineering Education, 58, 818-821, April 1968.

Technical and Scientific Reports

Jenny, J., Optimization of unmanned data collection systems, Tech. Rpt. No. 3433-1, NSF Grant 1195, SU-SEL-68-089, Stanford Electronics Laboratories, Stanford, California, December 1968.

Technical and Scientific Reports (continued)

Yu, W., Circuit synthesis utilizing digital-variable precision-integrating and summing elements, Sci. Rpt. No. 30, NGL 05-020-014, SU-SEL-68-084, Stanford Electronics Laboratories, Stanford, California, December 1968.

Tyler, G. L., The calculation of orbitally determined experimental parameters for bistatic-radar observations of Explorers XXXIII and XXXV from classical orbital elements, Tech. Rpt. No. 3609-2, NAS 5-9347, SU-SEL-68-059, Stanford Electronics Laboratories, Stanford, California, June 1968.

Tyler, G. L., A dual polarization bistatic-radar receiving system for Explorers XXXIII and XXXV, Tech. Rpt. No. 3609-3, NAS 5-9347, SU-SEL-68-008, Stanford Electronics Laboratories, Stanford, California, June 1968.

Barna, A., Pseudorandom frequency modulation in range-doppler radar, Sci. Rpt. No. 29, NsG 377, SU-SEL-68-046 and Tech. Rpt. No. 3606-4, Stanford Electronics Laboratories, Stanford, California, May 1968.

Burns, A. A., Lunar radar scattering at 6 and 12 meter wavelengths, Sci. Rpt. No. 25, NsG 377, SU-SEL-68-005, Stanford Electronics Laboratories, Stanford, California, May 1968.

Thiede, E. C., Locating refractive index variations with bistatic-radar, Sci. Rpt. No. 27, NsG 377, SU-SEL-68-037, Stanford Electronics Laboratories, Stanford, California, May 1968.

Lusignan, B. B., A preliminary study of atmospheric density measurements by means of satellites, Final Report, NAS 9-7020, SU-SEL-68-038, Stanford Electronics Laboratories, Stanford, California, April 1968.

Jenny, J. A., W. F. Lapson, Feasibility study of an automated unmanned geophysical observatory for operation in Antarctica, Tech. Rpt. No. 3431-1, NSF Grant 1195, SU-SEL-68-010, Stanford Electronics Laboratories, Stanford, California, February 1968.

Barna, A., Pseudorandom frequency modulation in range-doppler radar systems, Sci. Rpt. No. 26, NsG 377, SU-SEL-68-022, Stanford Electronics Laboratories, Stanford, California, February 1968.

Tyler, G. L., A. M. Peterson, Report on Monitoring AIMP-D Stanford AIMP Telemetry Monitoring Experiment, Tech. Rpt. No. 3609-1, NAS 5-9347, SU-SEL-68-006, Stanford Electronics Laboratories, Stanford, California, January 1968.

Spira, P. M., On the Time Required for Group Multiplication, Sci. Rpt. No. 24, NsG 377, SU-SEL-68-003, Stanford Electronics Laboratories, Stanford, California, January 1968.

Symposia Attended and Papers Presented

Nowak, R., On the relationship between decay rate of radar echoes from meteor trails and their height, American Geophysical Union Meeting, San Francisco, 2 December 1968.

Nowak, R., The measurement of upper atmosphere parameters with a meteor radar, American Meteorological Society, El Paso, 6 November 1968.

Miles, R. B. and B. B. Lusignan, DEMETER, an Earth resources satellite program, Proceedings of the 19th Congress of IAF, New York City, October 1968.

Lusignan, B. B., Education satellite technology, Proceedings of the 19th Congress of IAF, New York City, October 1968.

Eshleman, V. R., Bistatic radar studies of planetary atmospheres and surfaces, G-AP/URSI Symposium, Boston, 10 September 1968.

Tyler, G. L., Short course: Imaging radar, University of Michigan, Ann Arbor, July 1968.

Howard, H. T., Mariner V experimenter data workshop, University of Iowa, June 1968.

Tyler, G. L., Past results and future experiments in radar scattering, NASA-Ames Conference on Electromagnetic Exploration of Moon, Moffett Field, June 1968.

Lusignan, B. B., Density measurement with radio wave occultation techniques, COSPAR (Communications on Space Research), Tokyo, 9-21 May 1968.

Lusignan, B. B., AIAA - Systems Engineering, Houston, 20 May 1968.

Eshleman, V. R., G. Fjeldbo, Radio occultation and the atmospheres of Venus and Mars, AGU, Washington, D. C., 8-11 April 1968.

Staff, Center for Radar Astronomy at Stanford University, The Mariner-Venus dual-frequency radio occultation experiment: current interpretation, AGU, Washington, D. C., 8-11 April 1968.

Tyler, G. L., Preliminary bistatic-radar results from Explorer XXXV, AGU, Washington, D. C., 8-11 April 1968.

Fjeldbo, G., V. R. Eshleman, Mariner V low frequency occultation, Second Arizona Conference on the Planetary Atmospheres, Tucson, 11-13 March 1968.

Fjeldbo, G., A. Kliore, I. S. Rasool, Mariner V S-band occultation (with respect to upper atmosphere), Second Arizona Conference on the Planetary Atmospheres, Tucson, 11-13 March 1968.

Symposia Attended and Papers Presented (continued)

Lusignan, B. B., The Arctic Institute of North America Symposium on remote sensing in the polar regions, Washington, D. C., 6-8 March 1968.

Spira, P. M., On the time required for group multiplication, Hawiian International Conference on Systems Sciences, 29-31 January 1968.